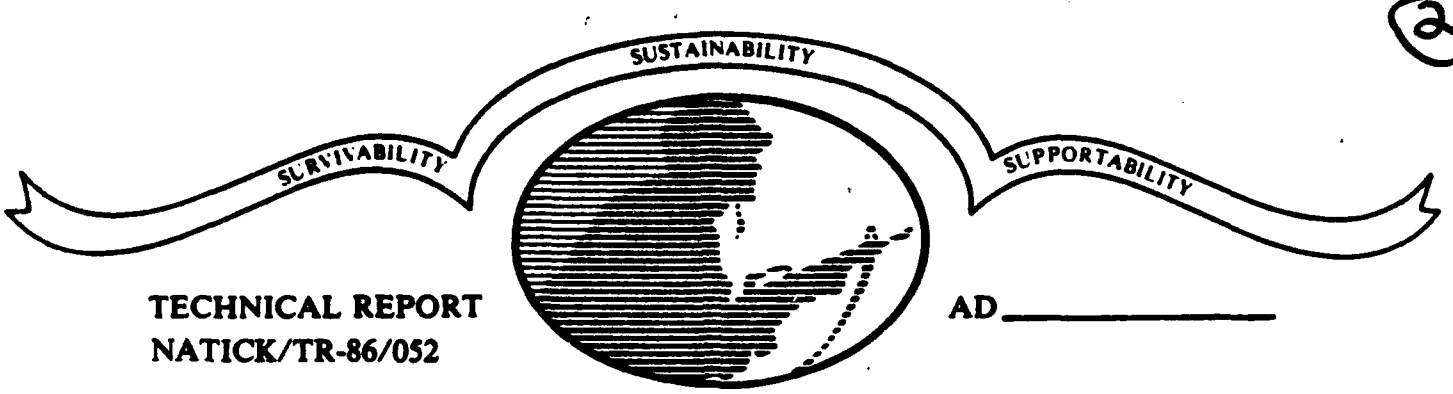

TECHNICAL REPORT
NATICK/TR-86/052

AD_____

DEVELOPMENT OF FIRE-RESISTANT TENTAGE FABRICS

BY

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In order to develop a fire-resistant tentage fabric, candidate fabrics were woven of spun yarns blended with mixtures of a brominated aromatic polyester (BRAPE) and commercial polyethylene terephthalate (PET). A comparison of the physical properties of the candidate fabrics led to the selection of a plain weave fabric from 20/1 cotton count yarns containing 35% BRAPE and 65% PET. A 50-yard sample of this fabric was submitted to Natick for test and evaluation prior to the weaving of a 300-yard length of the preferred candidate.

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SUMMARY

As a part of Phase I, it was originally planned to examine eight fabric variables in accordance with a factorial experiment. The performance of the eight experimental fabrics was to be compared against a control fabric constructed with the same yarn count and weave as in the standard 100% cotton tentage fabric in current use by the Army. Two blends of Brominated Aromatic Polyester (BRAPE)/Polyethylene Terephthalate (PET) were prepared for the experimental fabrics and each spun into 20/1 c.c. and 26/1 c.c. yarns. However, because of the limited amounts of BRAPE/PET yarns, the proper application of sizing on the commercial slashing equipment was hindered and difficulties were encountered in subsequent attempts to weave the eight various fabric constructions specified in the factorial design. As a result, only two swatches of experimental fabrics were produced. The two fabrics were constructed from 20/1 c.c. yarns composed of 35/65 and 25/75 BRAPE/PET and woven to a 2x1 twill.

Based on the yarn properties of the two blends (35/65 and 25/75) in both 20/1 and 26/1 c.c., and the two experimental fabrics, the 35/65 BRAPE/PET blend in the 20/1 yarn was selected to weave a 50-yard length of fabric in a plain weave construction. In addition, depending upon yarn availability, two additional fabric constructions are planned; one 2x1 twill and the other, 2x2 basket weave. An optimum construction will be selected after evaluation by the Army and a 300-yard length prepared for Phase II.

PREFACE

This report was written by Dai W. Kim, Senior Research Engineer, Celanese Research Company. The work reported herein was performed during 1981 - 1982 under Contract DAAK60-81-C-0061, "Development of a Fire Resistant Tentage Fabric," and was sponsored by the Individual Protection Laboratory of the U. S. Army Natick Research and Development Laboratories,* Natick, Massachusetts, under Project No. 1L162723AH98-CB-019. Calvin Lee was the Project Officer and his assistance and guidance are acknowledged; Thomas Jacques was the Contracting Officer.

Besides D. W. Kim who served as Principal Investigator, Nancy Rapp of Celanese Fibers Marketing Company, Charlotte, North Carolina, supervised textile fabrication processes and the dyeing and finishing operations at American Waterproofing Company, St. Louis, Missouri. The contributions of Dr. J. R. Leal, Dr. A. J. Rosenthal and Dr. B. S. Sprague, who served on the Advisory Board, are noted. The technical supervision and management of Frank Berardinelli and Michael Jaffe continued throughout the project. Dr. J. R. Leal, Senior Staff Associate, was the Contract Administrator.

This is the Final Technical Report issued under Phase I of Contract DAAK60-81-C-0061 and was submitted by the author in January 1982.

*Renamed 1 Oct 85 U. S. Army Natick Research, Development and Engineering Center.

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I. INTRODUCTION

The current Army tentage fabric is woven from cotton and requires an addition of approximately 4 oz/yd^2 of chemical coating to achieve fire retardancy, waterproofing and mildew and rot resistance. Modern synthetic fibers offer an opportunity to develop new tentage fabrics with lighter weight, improved performance and lower costs. To this end, Celanese proposed to develop an improved lightweight tentage fabric to replace the wind, fire and water resistant cotton fabric which is described in MIL-C-12095F. Blends of a brominated aromatic polyester (BRAPE) fiber with conventional polyester (PET) were considered for this development. The brominated aromatic polyester is a load-bearing fiber intended to impart flame retardancy to the cloth.

The proposed work was to be accomplished in two phases. In Phase I, planned for completion in eight months, the effects of fiber blend compositions, yarn size and fabric constructions on the physical and water repellency properties of the fabrics were investigated. This report and a 50-yard sample of the best candidate fabric comprise the deliverables under Phase I.

After the properties of the 50-yard sample delivered under Phase I have been verified and evaluated, the Contracting Officer will approve or deny commencement of Phase II.* Under Phase II, a 300-yard length of the selected candidate fabric will be prepared and delivered for further test and evaluation by the Army Natick Research and Development Laboratories.

*Phase II was not subsequently undertaken.

II. PROGRAM OBJECTIVES AND DEVELOPMENTAL PROGRAM

It is the objective of this project to develop an improved lightweight tentage fabric weighing less than 9 oz/yd^2 finished that can be considered for replacement of the wind, fire and water resistant cotton tentage fabric (~13 oz/yd^2 finished) which is described in MIL-C-12095F. Blends of BRAPE and polyethylene terephthalate (PET) will be used for the development. There are two phases to complete this project. Phase I is to study the effects of fiber blend compositions, yarn size and fabric constructions on the physical and water repellency properties and culminate in delivery of a 50-yard sample of the best candidate. Phase II is to submit a 300-yard sample of tentage fabric upon the approval of Phase I material by the Contracting Officer.

To pursue the Phase I objective, a factorial design experiment, as shown in Figure 1, was established. To conserve the limited quantity of BRAPE fiber, 5-yard long, 10-inch wide fabrics were to be woven for each experiment for determining physical properties, air permeability and water repellency. From these evaluations, an optimum tentage fabric construction was to be selected. The selected construction would then be made up in a 50-yard length for delivery. As discussed later, the original plan was abandoned and only two experimental fabrics were produced.

The final fabric selected in this program should conform with the desired properties indicated in Table 1.

	EXPERIMENTS				CONTROL
YARN SIZE (COTTON COUNT)	20/1		26/1		40/2
BRAPE BLEND (%)	25	35	25	35	35
TWILL (82x68)	XP-1	XP-2	XP-3	XP-4	NATICK WEAVE CONST.
PLAIN (80x64)	XP-5	XP-6	XP-7	XP-8	

Note: TM for yarns = 3.56
For the blend, polyester type -310
Twill fabric, 2x1 R.

FIGURE 1. Factorial experiment to design optimum tentage fabric construction

TABLE 1. Desired Tentage Properties and Federal Standard Test Method

Property	Requirement	Fed. Std. 191A Test Methods
Color	OG107	-
Colorfastness		
Weathering (min)	good	5671
Crocking (Munsell value) (max)	7.0	5651
Weight (oz/yd^2) (max)	9.0	5041
Breaking Strength (lbs) (min)		
Warp	175	5100
Filling	150	5100
Tearing Strength (lbs) (min)		
Warp	6.0	5132
Filling	6.0	5132
Spray Rating (min)	90, 90, 80	5526
Hydrostatic Pressure (cm) (min)		
Initial	45	5514
After Weathering	45 a	5804, 5514
Dynamic Absorption (%) (max)	25	5500
Air Permeability (cfm) (max)	2.0	5450
After-Flame (sec) (max)		
Initial	2.0	5903
After (3) Launderings	2.0	5556, 5903
After Weathering	2.0 a	5804, 5903
Char Length (in) (max)		
Initial	5.0	5903
After (3) Launderings	5.0	5556, 5903
After Weathering	5.0 a	5804, 5903
Seam Efficiency (%) (min)	75	5110
Flexibility (in, lbs) (max)		
Warp (initial)	0.015	5202
Filling (initial)	0.015	5202
Warp (low temperature)	0.030	5202 at 0° ±5°F
Filling (low temperature	0.030	5202 at 0° ±5°F
Light Transmission	nil	b

a. Although not to be considered as a requirement of this contract, the finished fabric should be capable of retaining these values after 18,000 langleys exposure to natural weathering at the US Army Tropic Test Center, Panama.

b. There is no test method in Fed. Std. 191A for measurement of light transmission through fabrics. A light box/photometer configuration has been found to be very suitable for measuring the portion of incident light transmitted through various fabrics.

III. TECHNICAL DISCUSSION

A. EXPERIMENTAL

1. Factorial Experiment Design

a. BRAPE/PET Blends. An experimental quantity of about 10 lbs of BRAPE fiber (1.5 inches long, 1.5 denier) was blended with polyester Type 310 (a commercial product made for industrial application, 1.5 inches long, 1.5 denier) in two ratios: 25/75 and 35/65 (% weight) BRAPE/PET. Fibers were tested for tenacity and elongation, employing an Instron tensile tester prior to yarn processing in order to ensure appropriate quality.

For each blend ratio, 20/1 and 26/1 cotton count yarns were spun. The yarns were tested for evenness using an Uster Evenness Tester. The yarns were also tested for tenacity, elongation and single-end-break followed by hot-air-shrinkage, shrinkage force and boiling-water-shrinkage. In addition, a 40/2 c.c. yarn of 35/65 BRAPE/PET was spun for use as the control and to weave a fabric employing the construction of the present 100% cotton tentage fabric in use by the Army.

b. Fabrication Process. Due to the small quantity of yarn prepared to weave the 10-inch wide, 5-yard lengths of experimental fabrics, yarn sizing (slashing) had to be by-passed and the yarn was beamed and harnessed on a Draper mini-loom for weaving. The fabrics were then dyed and finished (water repellency) prior to subjecting them to selected tests.

c. Optimum Fabric Selection. In the original plan, test data were to be programmed into a computer and evaluated by using a contour mapping technique and other pertinent statistical methods to determine an optimum fabric construction. Of the target requirements, flammability and water repellency were to be weighted as most important parameters. Because it was not possible to make the eight experimental fabrics as originally planned, a selection was made from a comparison of the yarn and fabric properties of two fabrics.

B. TECHNICAL DISCUSSION

1. Factorial Design

As a first step in this program, a small factorial experiment was designed. The experiment design included BRAPE level, yarn size and fabric construction parameters. In following the design, two yarn sizes in each of the two BRAPE/PET compositions were to be woven into two fabric constructions. The resulting eight experimental fabrics were to be compared against a control fabric constructed with the same yarn count and weave as is being used in the present 100% cotton tentage fabric. For reasons that will be described later, it was not possible to complete the experiment as planned and only two experimental fabrics were made. A selection between the two was made by comparing the yarn and fabric properties.

Reasons for selecting fiber types, yarn sizes and

fabric constructions to carry out the factorial design were as follows.

a. BRAPE Flame Retardant Fiber. Celanese has developed a flame retardant fiber from a brominated aromatic polyester which contains 46% bromine. BRAPE was developed through a pre-pilot stage as a candidate flame retardant fiber to blend with polyester/cotton for general wearing apparel. The program was shelved because of a change in the civilian marketplace resulting from a shift in the priorities of the Consumer Product Safety Commission. The fiber is durable, white, dyeable, and is indeed an acceptable textile fiber. It imparts flame retardancy to otherwise flammable fibers with which it is blended. BRAPE is not a char-forming polymer such as PBI, and therefore it is not a protective barrier against flame. Instead, it functions by emitting flame-quenching, bromine-containing gas, which snuffs out any incipient ignition. The amount of BRAPE required in any given fabric depends on the other fibers with which it is blended and its blend ratio and the specified degree of flame resistance required.

Approximately 30 lbs of BRAPE polymer were spun into 1.5 denier per filament (dpf) fiber, crimped for 12 crimps per inch, 26% crimp level, and cut to 1.5 inch staple length. A Celanese high tenacity polyester staple fiber, Type 310, 1.5 dpf and 1.5 inch cut length was chosen to be blended with BRAPE.

This type of staple is a commercial product with many established uses in industrial products applications. Table 2 exhibits the close similarities in the basic fiber properties of the two fiber types. As expected, because of its bromine content, BRAPE fiber has lower tenacity (2.8 grams per denier (gpd) vs 5.8 for Type 310) and slightly lower modulus (37 gpd vs 45).

Past studies have shown that 4 oz/yd^2 fabrics made from 40/60 BRAPE/PET blends meet Federal Test Method 5903 flammability requirements for apparel. However, lower BRAPE levels were chosen for this program to increase yarn and fabric strengths. For the tentage application, maximum strengths are desirable.

b. Yarn Size and Fabric Construction. Not only the fiber types but also yarn size and fabric construction can affect fabric properties and end-use performance. For example, within the polyester class, some yarns are available with higher strength and lower elongation than other polyester yarns. The stronger yarn would be expected to give a fabric with greater breaking and tear strengths, but lower resistance to abrasion and less flexibility. Yarn size coupled with weave pattern, i.e., sateen, twill or plain, also affects fabric properties and performance, but in a less predictable way. Also, yarn size directly influences how many ends per inch (EPI) and picks per inch (PPI) can be accommodated in the fabric. These factors, in turn, are related to rain resistance, air permeability, light transmission and physical properties. Studies to determine all of the relationships between yarn size/weave pattern and fabric properties could demand an effort that is beyond the scope of this project.

TABLE 2. Staple Fiber Properties of BRAPE vs PET Type 310

	BRAPE	PET
Tenacity grams/denier	2.8	5.8
Elongation %	24	26
Initial Modulus grams/denier	37	45
Crimps Per Inch	12	12
Crimp %	26	28
Denier g/9000 m	1.5	1.5
Staple Length inches	1.5	1.5

2. Effects of Short-Term Study

Thus, for this project, it was an intention to determine important effects in a short-term study. Such a study could help to identify an optimum fabric construction with BRAPE/PET blend yarns. To this end, two yarn sizes were chosen. A 20/1 cotton count yarn is very economical in textile processing and it was to be compared directly against 40/2 c.c. (used in the present 100% cotton tentage fabric). The other yarn size 26/1, was chosen to compare the effect of yarn size difference on fabric properties. Weave patterns of twill (2x1) and plain were selected to maximize fabric strengths and dimensional stability and were to compare against the sateen weave of the present tentage.

3. Spun Yarns of 20/1 and 26/1 c.c.

To carry out the factorial experiment, approximately 10 pounds of BRAPE staple fiber were blended with polyester Type 310 in 25/75 and 35/65% weight ratio in the hopper prior to carding. A minor electrical static problem was encountered in the carding, roving and spinning. The BRAPE, which had no lubricant finish, apparently caused the static but no special treatment was required to complete the yarn spinning. Preliminary quality inspections of the yarns (a part of the routine quality assurance program exercised at the Charlotte Textile Laboratory, Celanese Fibers Marketing Company), indicated that all yarns surpassed commercial standards for defect count and uniformity.

Prior to weaving, properties and shrinkages were determined. The results are listed in Table 3. Tenacity (tested by Instron Tensile Tester) and single-end-break factor (determined by Uster Automatic-Feed Single-End-Tensile Tester) were employed to determine the yarn strengths. Both tests indicated that the 25/75 BRAPE/PET, which contains less of the weaker BRAPE fiber, are slightly

TABLE 3. Yarn Properties of 25/75 & 35/65 BRAPE/PET Blend in 20/1 & 26/1 Cotton Count

BRAPE/PET	25/75		35/65	
Yarn, Cotton Count	20/1	26/1	20/1	26/1
Tenacity, g/d	3.0	2.9	2.8	2.6
Elongation, %	15.5	14.8	13.9	13.1
Single-End-Break Factor	4386	4132	3955	3557
%Coeff. of Var.	11.9	15.6	12.3	15.9
Hot Air Shrinkage, %	6.7	4.8	6.4	5.6
Hot Air Shrinkage Force, g/d	0.029	0.022	0.022	0.026
Boiling Water Shrinkage, %	0.6	0.9	1.0	1.1

but consistently stronger than the 35/65/blend. The lower elongation with the 35/65 blend is also expected from the lower fiber elongation displayed by the BRAPE. This lower elongation could become an advantage for the tentage application for the reason of greater dimensional stability in the fabric. Except for these, the two blends did not show any signigicant differences in other measured properties.

When the two yarn sizes were compared without regard to the blend levels, the 20/1 c.c. yarns consistently showed greater yarn strength with better uniformity based on % coefficient of variation (CV) values of single-end-break factor. This result is in line with a general rule that the coarser the yarn size, the greater the strength and uniformity in spun yarn. In addition, it is also true that the coarser the yarn, the more economical it is to produce

4. Experimental Fabrics

Preparatory to weaving, the spun yarns had to be sized on a slashing machine. When this process was initiated, it was discovered that the yarn lengths were too short to accommodate the minimum amount of yarn required by the commercial scale full size slashing machine. Therefore, a decision was made to by-pass the process. Weaving was done on a Draper mini-loom. However, the weaving became nearly impossible. The difficulty involved "yarn break-outs" caused by fiber entanglements of warp ends closely harnessed on the loom. Changes in fabric construction by reducing the end count and applications of various starch sizes and other materials (domestic starch spray, hair spray, etc.) to bind the fibers protruding on the surface of the yarns were examined as a means to eliminate or minimize the problem. None of these efforts was successful. After a prolonged trial, two 10 inch x 1 yard fabric samples were salvaged. They were 25/75 and 35/65 blends in a 2x1 twill construction using the 20/1 c.c. yarn. Weaving with the 26/1 yarn was considerably more difficult and no fabric sample could be made.

The two fabric samples were then tested prior to dyeing and finishing for flammability test only. These results are displayed in Table 4. The key properties of the fabric samples tested were flame resistance according to Federal Test Method 5903[1] before and after the wet process-dyeing and water repellency treatment. As the results show, the fabric samples surpassed the requirement with ease, both before and after wet processing. The air permeability of the fabric samples in the greige stage seemed to be slightly higher than desired in order to achieve less than 5 ft^3/ft^2 per min in the finished fabric. This was due to the need to reduce the number of ends in the warp (EPI) to avoid fiber-entanglement and yarn break-outs. The finished fabric samples would be expected to give lower air permeabilities, but the sample sizes were too small and the test could not be conducted.

5. 50-Yard Tentage Fabric

Approximately 50 lbs of 35/65 BRAPE/PET blend 20/1 c.c. yarn have been spun. The yarn quality is within the commercial acceptance level. The yarn was sized on a commercial slasher and is being prepared for weaving. It is expected that about 70 yards of plain weave construction (36 in width) will be obtained. The greige fabric will be tested for weight, air permeability, flame resistance, and tear strength prior to dyeing and finishing at American Waterproofing Company. Complete testing will be conducted on the finished fabric prior to its delivery to Natick on or about February 22.

The decision to select the 35/65 blend level, the 20/1 yarn size and plain weave pattern was primarily based on the data discussed above and work experience with 100% PET tentage.

TABLE 4. Properties of Experimental Fabrics[a]

I.D.	XP-1	XP-2
BRAPE/PET	25/75	35/65
Greige Fabric		
Weight, oz/yd^2	6.1	6.3
EPI x PPI	82 x 68	82 x 68
Air Permeability ft^3/ft^2 per min	22	20
Flame Resistance, Warp x Filling		
Char Length, in.[b]	3.5 x 3.2	3.1 x 3.1
After-flame, sec.[c]	2 x 0	0 x 0
Dyed/Finished Fabric Water Repellent		
Flame Resistance, Warp x Filling		
Char Length, in.[b]	2.4 x 2.8	2.0 x 2.2
After-flame, sec.[c]	0 x 0	0 x 0

a 2x1 Twill, 20/1 c.c. yarn

b 5x5 requirement

c 2x2 requirement

The 30/65 BRAPE/PET blend offers the assurance of satisfactory flame resistance which is the most important parameter of this tentage development project. This blend level did not degrade yarn strength significantly when compared to the 25/75 blend yarn. The 20/1 c.c. yarn size was chosen for its substantially better yarn uniformity. The plain weave fabric construction was to provide better dimensional stability.

In addition to the 50-yard sample, it is planned to weave, depending upon yarn availability, 20-yards each of 2x1 twill and 2x2 basket weaves. These will be tested before and after dyeing and finishing in order to acquire additional information and to help in deciding upon optimum fabric construction to produce the 300-yard sample planned for Phase II. These fabric properties will be compared to the properties of 100% cotton tentage fabric which was tested by Celanese. The results, are displayed in Table 5.

TABLE 5. Properties of Finished 100% Cotton Tentage Fabric[a]

EPI x PPI	115 x 92
Air Permeability, ft^3/ft^2 per min	8.2
Breaking Strength (lbs)	
Warp	201
Filling	155
Breaking Elongation (%)	
Warp	7.4
Filling	17.6
Tearing Strength (lbs)	
Warp	4.2
Filling	4.3

[a] Obtained from Natick R&D Labs and tested at the Celanese Fibers Marketing Company test laboratories in accordance with Federal Standard 191A Test Methods shown in Table 1

IV. CONCLUSIONS

The goal of this work was to produce a fire resistant tentage fabric meeting the physical property requirements listed in Table 1 at a weight of less than 9 oz/yd^2. The flammability requirement was met and the weight will be less than the specified target.

The yarn size 20/1 c.c. is a superior product over the 26/1 c.c. in terms of yarn uniformity and defect count.

V. RECOMMENDATIONS

It is recommended that 2x1 twill and 2x2 basket weave fabrics be completed following the 50 yards of plain weave sample submitted to Natick.

The additional fabrics should be tested before and after wet processing to aid in deciding upon an optimum construction for the final 300-yard sample.

The use of PBI polybenzimidazole fiber as a substitute for the 35/65 BRAPE/PET should be explored.

This document reports research undertaken in cooperation with the US Army Natick Research, Development and Engineering Center under Contract No. DAAK60-81-C-0041 and has been assigned No. NATICK/TR-82/052 in the series of reports approved for publication.

REFERENCE

1. Federal Test Method 5903 "Flame Resistance of Cloth; Vertical", 20 July 1978.